

Evapotranspiration from a Satellite-Based Surface Energy Balance for the Snake Plain Aquifer in Idaho

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EVAPOTRANSPIRATION FROM A SATELLITE-BASED SURFACE ENERGY BALANCE FOR THE SNAKE PLAIN AQUIFER IN IDAHO¹

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ABSTRACT

METRIC™ (Mapping Evapotranspiration at high Resolution and with Internalized Calibration) is an image-processing tool for calculating ET as a residual of the energy balance at the earth's surface. METRIC™ is a variant of the important model SEBAL, an energy balance model developed in the Netherlands and applied worldwide by Bastiaanssen. METRIC™ has been extended to provide tighter integration with ground-based reference ET and has been applied with Landsat images in southern Idaho to predict monthly and seasonal ET for water rights accounting and for operation of ground water models. METRIC™ has also had limited application in the Imperial Valley of Southern California. ET "maps" (i.e., images) provide the means to quantify, in terms of both the amount and spatial distribution, the ET on a field by field basis.

Results from METRIC™ have been compared and validated using precision-weighing lysimeter measurements from the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) at Kimberly, Idaho, and from Utah State University for the Bear River. ET for periods between satellite overpasses was computed using ratios of ET from METRIC™ to reference ET computed for ground-based weather stations. ET maps via METRIC™ provide the means to quantify, in terms of both the amount and spatial distribution, ET from individual fields. The ET images generated by METRIC™ show a progression of ET during the year as well as distribution in space.

Initial application and testing of METRIC™ indicates substantial promise as an efficient, accurate, and relatively inexpensive procedure to predict the actual evaporation fluxes from irrigated lands throughout a growing season. ET from satellite images may replace current procedures used by Idaho Department of Water Resources and other management entities that rely on ground-based ET equations and generalized crop coefficients that have substantial uncertainty.

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INTRODUCTION

METRIC™ and SEBAL represent an emerging technology that has the potential to become widely adopted and used by the world's water resources communities. ET maps created using METRIC™, SEBAL or similar remote-sensing based processing systems will some day be routinely used as input to daily and monthly operational and planning models for reservoir operations, ground-water management, irrigation water supply planning, water rights regulation, and hydrologic studies.

In Idaho, METRIC™ has been used to generate monthly and seasonal ET maps for predicting effects of irrigation on stream flow depletion in the Bear River Basin and the upper Snake River Basin. The ET maps are also used to predict recharge to ground-water systems and to extend pumpage records for ground-water diversions. The Snake River Plain aquifer system is large, spanning more than 30,000 square km (an area larger than the states of Massachusetts, Connecticut, and Rhode Island combined), with over 7,000 square km (1.7 million acres) of irrigated farmland.

Two METRIC™ applications have been made in Idaho using funding from Raytheon Company and the National Aeronautics and Space Administration (NASA). The first application, during Phase I of the study, was to the Bear River Basin of southeast Idaho (Morse et al., 2000). The second application, during Phase II, was to the eastern Snake River Plain of southern Idaho, (Morse et al., 2001).

The theoretical and computational approaches of SEBAL and METRIC™ are described in Bastiaanssen et al., (1998), Bastiaanssen (2000), Morse et al., (2000) and Tasumi et al. (2004b). By using an energy balance at the surface, energy consumed by the ET process is calculated as a residual of the surface energy equation:

$$LE = R_n - G - H \quad (1)$$

where LE is the latent energy consumed by ET, R_n is net radiation (sum of all incoming and outgoing shortwave and longwave radiation at the surface), G is sensible heat flux conducted into the ground, and H is sensible heat flux convected into the air. The utility of using energy balance is that actual ET rather than potential ET (based on amount of vegetation) is estimated, so that reductions in ET caused by shortage of soil moisture are captured. Of course, the estimate of LE is only as accurate as the estimates of R_n , G, and H. The algorithms used in METRIC™ for R_n and G are similar to those described for SEBAL by Bastiaanssen et al. (1998) and the reader is referred there and to Tasumi et al. (2004b) for detail. Basically, R_n is computed from satellite-measured broad-band reflectances and surface temperature, G is estimated from R_n , surface temperature, and vegetation indices, and H is estimated from surface temperature ranges, surface roughness, and wind speed using buoyancy corrections.

METRIC™ differs from SEBAL principally in how the “H function” is calibrated for each specific satellite image. In both METRIC™ and SEBAL, H is predicted from an aerodynamic function where:

$$H = \rho C_p \frac{dT}{r_{ah}} \quad (2)$$

where ρ is air density, C_p is specific heat of air at constant pressure, and r_{ah} is aerodynamic resistance between two near surface heights (generally 0.1 and 2 m) computed as a function of estimated aerodynamic roughness of the particular pixel and using wind speed extrapolated to some blending height above the ground surface (typically 100 to 200 m), with an iterative stability correction scheme based on the Monin-Obukhov functions (Allen et al. 1996). The dT parameter represents the near surface temperature difference between the two near surface heights. Because of the difficulties in estimating surface temperature (T_s) accurately from satellite due to uncertainties in atmospheric attenuation and contamination and radiometric calibration of the sensor, dT is estimated as a relatively simple linear function of T_s :

$$dT = a + b T_s \quad (3)$$

Bastiaanssen (1995) and Bastiaanssen et al. (2004) provide rationale and empirical evidence for using the linear relation between dT and T_s . The application of (3) appears to extend well across a range of surface roughnesses, because as roughness increases and r_{ah} reduces, given the same H , dT reduces due to more efficient transfer of H , and T_s reduces for the same reason.

In most applications of SEBAL (Bastiaanssen et al., 1998), parameters a and b in (3) are computed by setting $dT = 0$ when T_s is at the surface temperature of a local water body (or in its absence, a well vegetated field) where H is expected to be zero, and by setting $dT = (H r_{ah})/(\rho C_p)$ at T_s of a “hot” pixel that is dry enough that one can assume that $LE = 0$. From (1) and (2), $dT = ((R_n - G) r_{ah})/(\rho C_p)$ at the “hot” calibration pixel. In METRIC™, the same approach and assumptions are made for the hot pixel as in SEBAL, although a daily surface soil water balance is run for the hot pixel to confirm that $ET = 0$ there or to supply a nonzero value for ET for the hot pixel for calibration of (3). For the lower calibration point of dT in METRIC™, a well vegetated pixel having relatively cool temperature is selected and dT at that pixel is calculated as:

$$dT = \frac{(R_n - G - k ET_r) r_{ah}}{\rho C_p} \quad (4)$$

The a and b coefficients are determined using the two values for dT paired with the associated values for T_s . With Landsat images, fields of alfalfa or other high leaf area vegetation can generally be identified that are close to or at full cover, so that the ET from these fields can be expected to be near the value of “reference ET ” (ET_r) computed for an alfalfa reference. In METRIC™, we use the standardized ASCE Penman-Monteith equation for alfalfa reference (ASCE-EWRI 2002), which is typically 20 to 30 percent greater than grass reference ET (ET_o). The k factor in (4) is set to 1.05 because we assume that a viewed field having high vegetation and colder than average temperature, as compared to other high vegetation fields, will have ET that is about 5% greater than ET_r due to higher surface wetness or merely due to its rank within the population of alfalfa fields (or other highly vegetated areas). Generally, METRIC™ is applied without crop classification, so that specific crop type is generally not known.

METRIC™ and SEBAL, when applied with Landsat images, generally differ somewhat in how ET for the adjoining 24-h period is estimated given the essentially instantaneous ET calculated at the time of the satellite image (generally during late morning). In SEBAL, the evaporative fraction (EF), defined as the ratio of ET to $(R_n - G)$, is assumed to be the same at both the observation time and for the 24-h period. The assumption of constant EF can sometimes underpredict 24-h ET in arid climates where afternoon advection or increases in afternoon wind speeds may increase ET in proportion to R_n . In METRIC™, the extrapolation from observation time to the 24-h period is done using the fraction of reference ET ($ET_r F$) rather than EF. $ET_r F$ is defined as the ratio of ET to ET_r (in the case of METRIC™, alfalfa reference), and is essentially the same as the well-known crop coefficient, K_c (for an alfalfa reference basis). The assumption of constant $ET_r F$ during a day may be better able to capture impacts of advection and changing wind and humidity conditions during the day, as expressed in the ET_r calculation (which is done hourly and summed daily). Trezza (2002) and Romero (2004) demonstrated the general validity of constant $ET_r F$ during a day using lysimeter data from Kimberly.

Primary reasons why METRIC™ and SEBAL are attractive to our applications in the western U.S. are:

- METRIC™ and SEBAL calculate *actual* ET rather than *potential* ET and do not require knowledge of crop type (no satellite-based crop classification is needed).
- METRIC™ and SEBAL rely heavily on theoretical and physical relationships, but provide for the introduction and automated calibration of empirical coefficients and relationships to make the process operational and accurate.
- The use of ET_r in calibration of METRIC™ and the use of $ET_r F$ in extrapolation to 24-h ET provides general equivalency and congruency with ET as estimated using the traditional $K_c ET_r$ (or $K_c ET_o$) approach. This is valuable for use of ET maps generated by METRIC water rights management where water rights are based on previous $K_c ET_r$ calculations.
- METRIC™ is auto-calibrated for each image using ground-based calculations of ET_r (made using weather data) where accuracy of the ET_r estimate has been established by lysimetric and other studies and in which we have high confidence.
- Internal calibration of the sensible heat computation within SEBAL and METRIC™ eliminates the need for atmospheric correction of T_s or reflectance (albedo) measurements using radiative transfer models (Tasumi et al. 2004a). The internal calibration also reduces impacts of any biases in estimation of aerodynamic stability correction or surface roughness.

BEAR RIVER APPLICATION

In 1958, the Bear River Compact was developed to establish how Idaho, Utah and Wyoming would equitably distribute and use water from the Bear River. The role of Idaho Department of

Water Resources (IDWR) is to compute depletion by irrigated agriculture for the Idaho part of the basin to support Idaho's position in negotiations with the other two states.

In Phase I (2000) of our study, ET maps were generated monthly for a 500 km x 150 km area (comprised of 2 Landsat images) encompassing the Bear River basin. Images were processed for 1985, coinciding with an ET study using lysimeters (Hill et al., 1989) that allowed for comparison to METRIC™. Lysimeters near Montpelier, Idaho, just north of Bear Lake, had been planted to an irrigated native sedge forage crop characteristic of the area and local surroundings. The lysimeters were measured weekly. ET from the three lysimeters was averaged to reduce random error and uncertainty in the ET measurements. Results for four satellite images during the 1985 growing season (July 14, Aug. 15, Sept. 16, Oct. 18) are summarized in Figure 1 and Table 1. The results compare well to lysimeter data for the last three image dates. The earliest date, July 14, compares well when examined in context of the impact of precipitation preceding the image date and rapidly growing vegetation during that period (Morse et al., 2000).

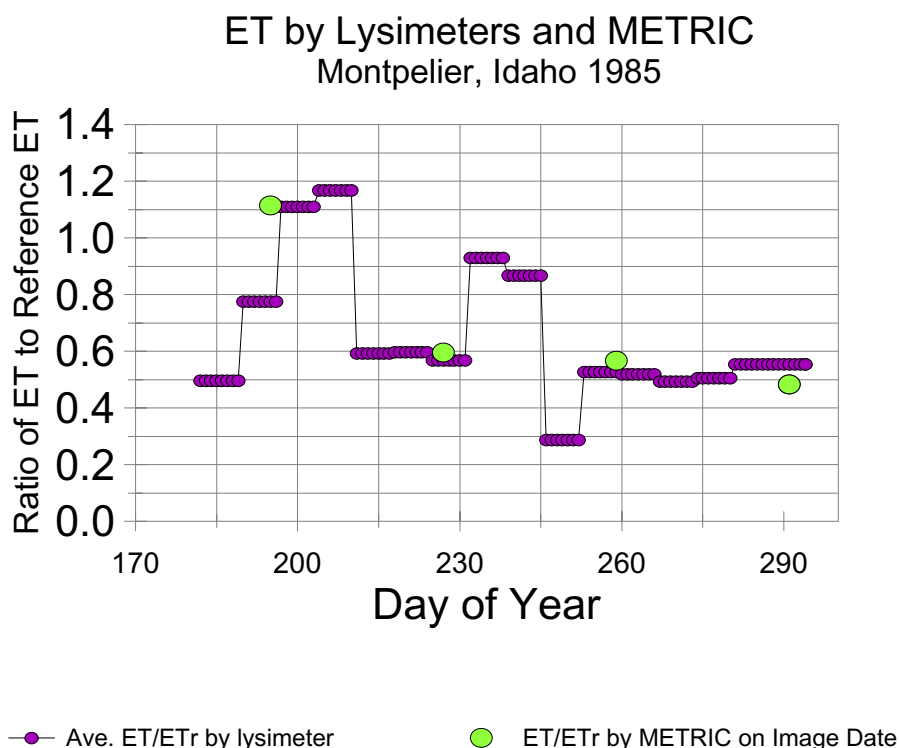


Figure 1. Comparison of ET_r fractions (i.e., K_c) derived from 7-day lysimeter measurements near Montpelier, Idaho during 1985 and values from METRIC™ for four Landsat dates (ET = crop ET and ET_r = alfalfa reference ET_r).

The Fraction of Reference ET (ET_rF) in Table 1 is defined as ET/ET_r where ET_r is reference ET based on an alfalfa-reference basis. ET_rF values were computed for each pixel and used to extrapolate ET from the day of the satellite image to days between images. ET_rF is synonymous with the well-known crop coefficient, K_c when applied to an alfalfa reference as the basis (as opposed to clipped grass ET_0). ET_r accounts for changes in ET caused by weather variation between satellite image dates.

Table 1. Summary of METRIC™ - and lysimeter-derived ET for weekly and monthly periods and the associated error for Bear River, 1985.

	7-day Lys. ET ave. for image date (mm d ⁻¹)	METRIC ET _r F on image date	7-day METRIC ET for image date (mm d ⁻¹)	Diff. in 7-day ET (METRIC – Lys) (%)	Monthly Alfalfa ET _r (mm)	METRIC ET (mm)	Lys. Monthly ET (mm)	Diff. in Monthly ET (METRIC – Lys.) (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(10)
July	5.3	0.98	6.8	28%	202	198	167	19%
Aug	3.5	0.59	3.7	6%	201	119	145	-18%
Sept	1.9	0.57	2.1	10%	115	66	54	22%
Oct	0.7	0.49	0.6	-14%	45	22	23	-5%
July- Oct.	2.9	0.73	3.3	15%	563	405	388	4%

Predicted monthly ET averaged +/- 16% relative to the lysimeter at Montpelier (Table 1). However, seasonal differences between METRIC™ and lysimeters were only 4% due to impacts of reduction in the random error component present in each estimate.

SNAKE RIVER PLAIN APPLICATION

Managing water rights and irrigation on the Snake River Plain and tributary basins presents a challenge to IDWR. Water for irrigation comes from surface and ground sources. For various historical reasons, the use of surface water has been directly measured and regulated by IDWR while the use of ground water has not. This situation began to change in 1995 when the Water Measurement Information System Program was established within IDWR to measure ground-water use. IDWR has dedicated considerable resources to water measurement, including three full-time positions to monitor about 5,000 points of diversion, mostly wells. As useful as these data are, they do not provide all the information necessary for effective management of the resource, nor do they include all irrigation wells. Information regarding the ET or consumed fraction of diversions is needed. METRIC™ or SEBAL can be used in conjunction with Water

Measurement data in an efficient program to help manage water development, use and stewardship. METRIC™ and SEBAL cover large areas inexpensively and efficiently, thereby extending Water Measurement data in both time and space, and the Water Measurement data, in turn, can be used to calibrate relationships based on METRIC™ or SEBAL results.

This combined program offers advantages over present methods: 1) it offers the ability to monitor whether water has actually stopped being used for irrigation after a water shut-off order has been issued; 2) it can discover if more water has been used than authorized; 3) it can quantify and be used as proof of beneficial use of a right; 4) it can be used as an unbiased, quantitative record of historical use; 5) the consumed fraction and return of non-evapotranspired water to the resource can be quantified; 6) estimates of yield and productivity can be made to assess benefits of water development and tradeoffs in water management. In addition, resulting seasonal ET maps are utilized by the State of Idaho, University of Idaho, and U.S. Bureau of Reclamation ground-water modelers to predict recharge of irrigation water to the Eastern Snake Plain Aquifer.

A number of tasks during Phases II - IV (2001-2003) were directed at improving components of METRIC™ to better predict ET for environments found in the western United States. These include prediction of net radiation and soil heat flux components and identification and assessment of the energy balance for “anchor” pixels used to define the overall energy balance for the image. Other improvements included determination of mean wind speeds in mountain areas, prediction of aerodynamic roughness for various vegetation covers, and development of an ET reference fraction (ET_rF) approach for extending ET between images (Allen et al., 2001).

The production of ET maps having 30 m resolution for the Eastern Snake River Plain Aquifer was highly successful. ET images were created for 12 dates during 2000 and were integrated over the March – October period. Interpolation between image dates was done using ET_rF from pixels of each image and multiplying these by ET_r computed for each day between images.

Images were purchased from both Landsat 5 and Landsat 7 archives for 2000 to increase the number available for the southern Idaho area. Often, dates for adjacent Landsat 5 and 7 paths were separated by just one day. Landsat 5 images were of immense value in providing ET for similar periods between paths. Algorithms were developed to correct individual reflectance bands of Landsat 5 to coincide with measurements by Landsat 7 to account for sensor deterioration.

Validation of METRIC at Kimberly, Idaho

The validation of METRIC™ on the Snake River Plain has centered on the use of two precision-weighting lysimeter systems for ET measurement in place near Kimberly, Idaho, from 1968 to 1991. The lysimeter system was installed and operated by Dr. James Wright of the USDA-ARS (Wright, 1982, 1996) and measured ET fluxes continuously. ET data are available for a wide range of weather conditions, surface covers, and crop types. Measurements of net radiation, soil heat flux and plant canopy parameters were frequently made near the lysimeter site. The lysimeter data sets provided valuable information to verify METRIC™ over various time scales and for various conditions of ground cover.

Nineteen Landsat 5 satellite image dates were purchased for Kimberly, Idaho, covering the period between 1986 and 1991. These dates had quality lysimeter and cloud-free micrometeorological data and represent a combination of crop growth stages and times of the year. Eight images from 1989 are discussed here.

The lysimeter data for intervening periods between image dates were used to assess the impact of various methods for extending ET maps from a single day to longer periods. They have also been used to assess the variability in ET_rF over a day. The success of METRIC™ is predicated on the assumption that ET_rF for a 24-hour period can be predicted from the ET_rF from the instantaneous satellite image. ET_r was calculated for hourly and 24-hour periods using the ASCE standardized Penman-Monteith method for an alfalfa reference (EWRI, 2002), representing the ET from a well-watered, fully vegetated crop, in this case, full-cover alfalfa 0.5 m in height. The denominator ET_r serves as an index representing the maximum energy available for evaporation. Weather data were measured near the lysimeter and included solar radiation, wind speed, air temperature and vapor pressure. Lysimeter data analyses showed $ET_rF = ET / ET_r$ to be preferable to the evaporative fraction (EF) parameter used in some applications of SEBAL (Bastiaanssen et al., 1998, Bastiaanssen 2000)), where $EF = ET / (R_n - G)$. The better performance by ET_rF was due to its consistency during daytime and agreement between hourly ET_rF at satellite overpass time (~1030) and daily average ET_rF . An illustration of ET_rF for a day in 1989 is given in Figure 2 for clipped grass (*alta fescue*) and sugar beets. ET_rF for many days was even more uniform than shown in the figure. In nearly all cases, the ET_rF for the 24-hour period was within 5% of the ET_rF at 1030.

Table 2 summarizes error between METRIC™ and lysimeter measurements during 1989, a year when a significant number (eight) of both lysimeter measurements of ET and Landsat images were available. Absolute error averaged 30% for the eight image days. When April 18 was omitted, the average absolute error was only 14%. April 18 was before planting of the sugar beets and represented a period of drying bare soil following precipitation. The field at this time was nonuniform in wetness due to differential drying, and differences between lysimeter and estimate were only 1 mm. The standard deviation of error between METRIC™ and lysimeter for dates from May – September was 13%. In comparison, a commonly quoted standard error for ET prediction equations that are based on weather data, for example, Penman or Penman-Monteith-types of equations, is about 10% for daily estimates. METRIC™ was able to obtain close to this level of accuracy for the field surrounding the lysimeter. Results are illustrated in Figure 3, where ET is expressed in the form of ET_rF . ET_rF was used to normalize results for differences in climatic demand (i.e. ET_r). The round symbols and horizontal line segments in Figure 3 represent ET_rF determined from lysimeter on the image date, only. These values are those directly comparable with METRIC™ predictions in Table 2. The triangular symbols in represent the ET_rF predicted by METRIC™ for the image date.

Table 2 summarizes the extrapolation of ET by METRIC™ over the season (April 1 – Sept. 30, 1989). Most periods were 16 days, centered on the image date. April 18 was used to represent April 1 – April 25, July 23 was used to represent July 16 to August 24 and Sept. 25 was used to represent Aug. 25 through Sept. 30. What is surprising is the close agreement for seasonal ET for April 1 – September 30. The difference between METRIC™ (714 mm) and the lysimeter measurement (718 mm) was less than 1% for the sugar beet crop. It appears that much of the

error occurring on individual dates was randomly distributed, and tends to cancel, as described in more detail in Allen et al., (2004).

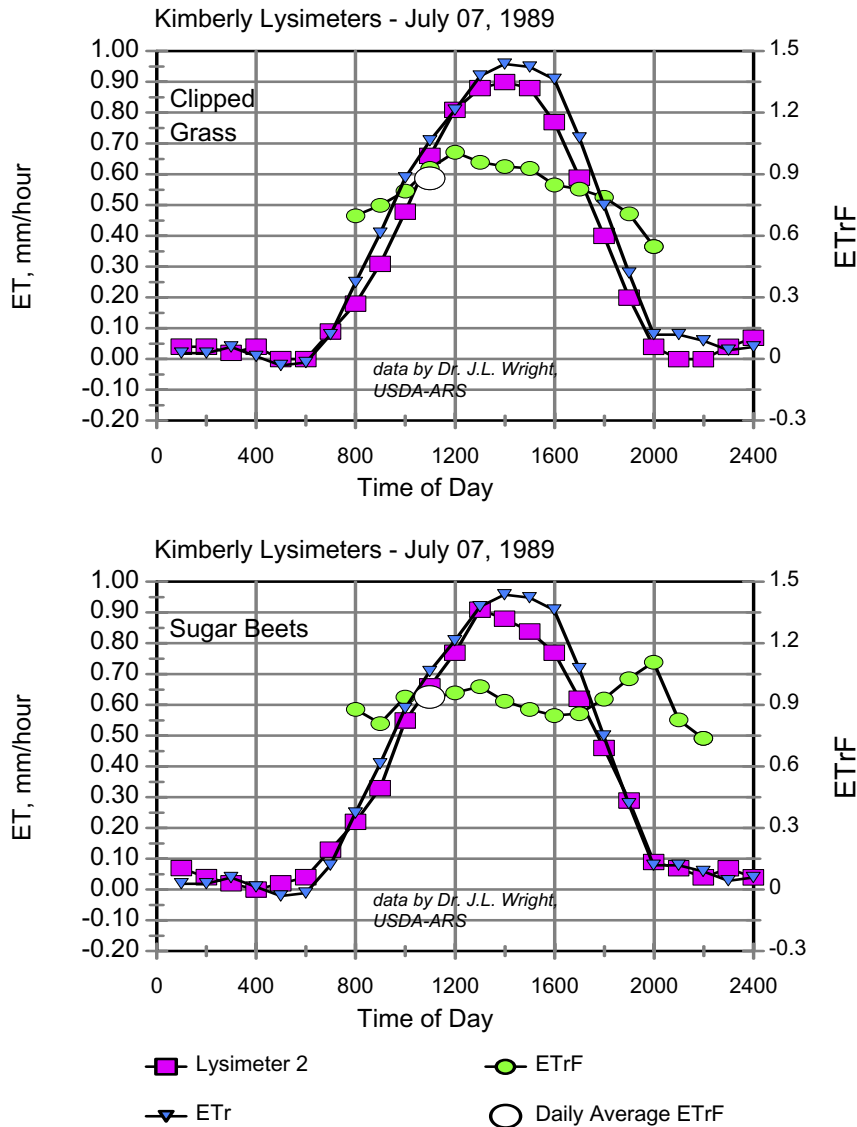


Figure 2. Hourly measured ET, ET_r, ET_rF and 24-hour ET_rF for July 7, 1989, for clipped grass (top) and sugar beets (bottom) at Kimberly, Idaho.

Table 2. Summary and computation of ET during periods represented by each satellite image and sums for April 1 – September 30, 1989, for Lysimeter 2 (Sugar Beets) at Kimberly, Idaho.

Image Date	Lys. ET on date (mm d ⁻¹)	METRIC ET on date (mm d ⁻¹)	Error on Image Date (%)	ET _r on date (mm d ⁻¹)	ET _r for period (mm)	Lys. ET summed daily for period (mm)	Lys. ET for period based on image date only (mm)	METRIC ET for period (mm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4/18/89	0.73	1.74	139	6.78	147	28	16	38
5/4/89	6.61	5.09	-23	7.76	94	30	80	62
5/20/89	1.37	1.34	-2	7.27	90	22	17	17
6/5/89	1.73	1.78	3	6.68	118	24	30	31
6/21/89	2.39	2.54	6	6.33	127	62	48	51
7/7/89	7.96	5.89	-26	8.44	120	116	113	84
7/23/89	7.64	7.17	-6	7.38	253	266	262	246
9/25/89	5.51	7.40	34	8.00	201	171	138	186
4/1–9/30						718 ^a	705 ^b	714 ^c
Percent Error						-----	-1.8%	-0.6 %

^a The sum of daily measurements by lysimeter computed as the sum over all days between April 1 and Sept. 30.

^b The sum of ET computed for each lysimeter period, computed by multiplying summed ET_r during the period by the ET_{rF} for the image date.

^c The sum of ET predicted by METRIC™ for the lysimeter 2 field, computed by multiplying the summed ET_r during the period by the ET_{rF} computed on the image date by METRIC™.

An illustration of the type of resolution for ET maps generated from Landsat imagery is shown in Figure 4 for a 4 km x 6 km area near American Falls, Idaho.

IMPERIAL VALLEY

Evapotranspiration maps were created using METRIC™ and Landsat 7 images for much of Imperial Valley, California, for the January-March periods of 2002 and 2003 (Allen et al., 2003). The application demonstrated the ability to produce maps of quantitative, spatial distribution of monthly ET in near real time with resolution on the sub-field scale.

IMPACT

The METRIC™ work is evolving. Nevertheless, there have been impacts. IDWR found the results of Phase I and II sufficiently compelling to request additional funding from the Idaho Legislature to include METRIC™ as the ET source for recalibration of the Eastern Snake River Plain aquifer model and to generate ET maps to monitor ground-water pumage. The aquifer model uses 5 km grid cells, and aggregating ET up to a 5 km cell is preferable to disaggregating county-averaged data.

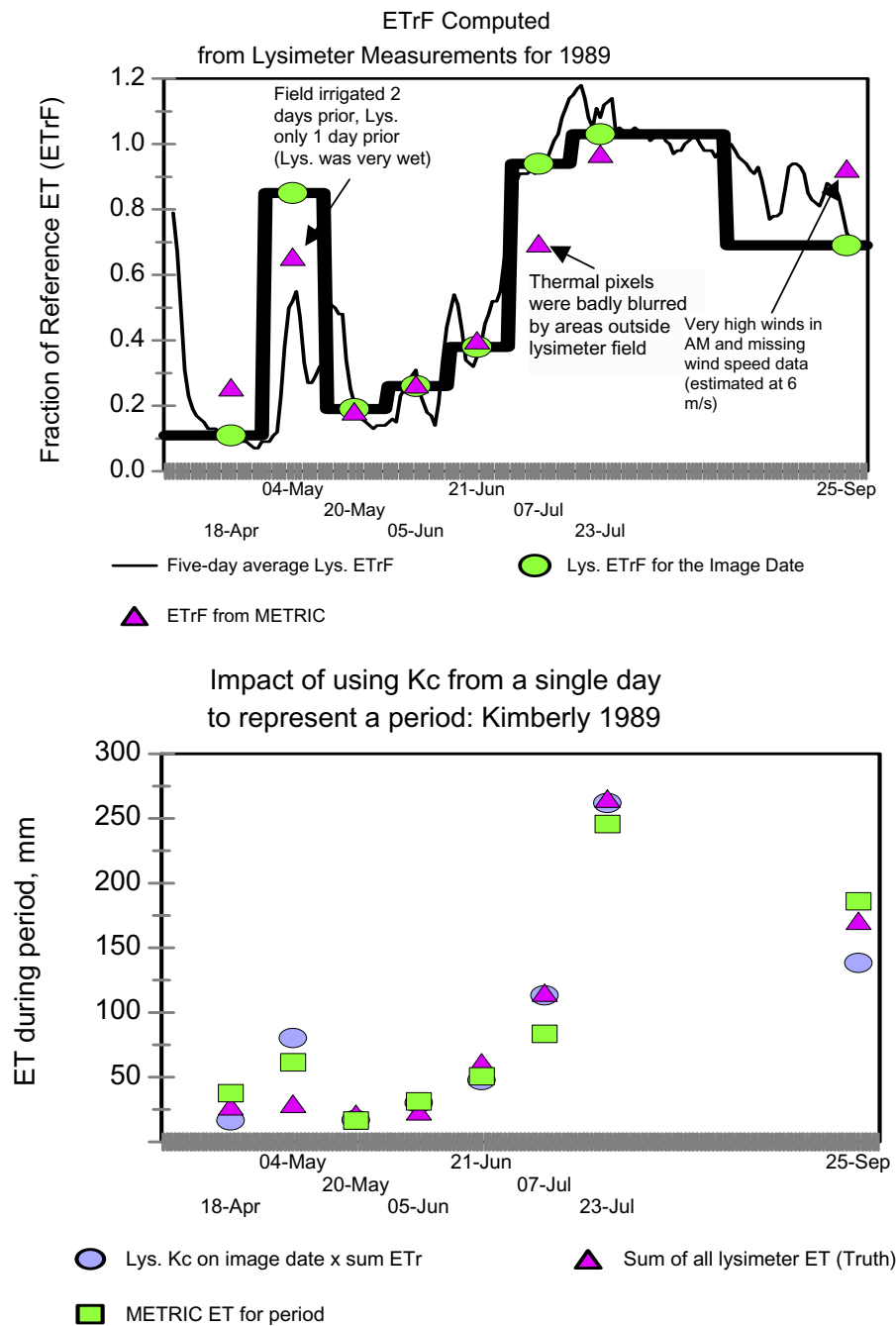


Figure 3. Results by METRIC™ and ET by Lysimeter as ET_rF (top). The thin line is the five-day average ET_rF for lysimeter and the thick line is the assumption used in that application to extrapolate between images. The bottom figure shows total ET for the image period.

COST SAVINGS

ET data derived from METRIC™ are less expensive to generate than are standard ET data. Since IDWR is still developing the METRIC™ data, a quantitative cost-benefit analysis is premature. Nevertheless, it is possible to do a rough cost comparison based on some available figures. Current costs for monitoring water use on the eastern Snake River Plain are estimated to be about \$500,000 per year. We estimate costs for remote sensing to be about \$100,000 per year. This includes costs for 30 TM scenes representing 8 to 10 dates for the whole eastern Snake Plain (Landsat scenes cost about \$400 each for images. Geo-registration of images costs an additional \$400 each, for a total procurement cost of about \$24,000, and about three Landsat images (100 miles x 100 miles) are required to cover the full area). Once set up for an area, METRIC™ processing requires about 8 days per scene (240 days * 8 hours = 1920 hours *

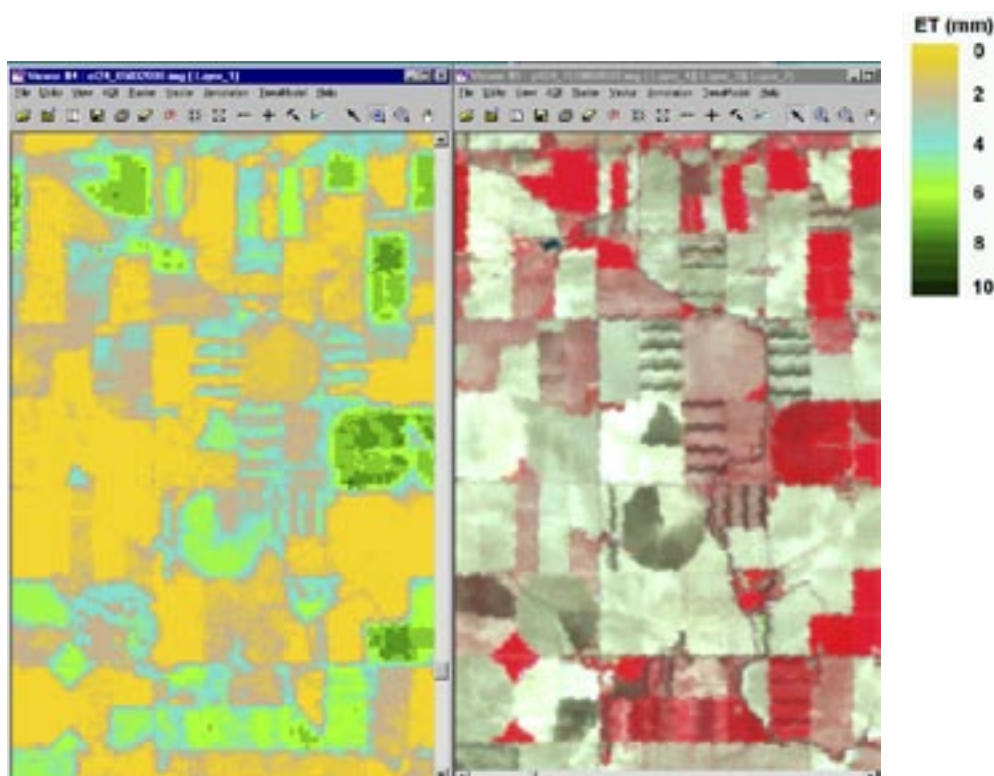


Figure 4. Close-up of ET (left) with false color composite (right) from Landsat 7 showing variation within individual fields May 5, 2000.

\$40.00 per hour = \$76,800 for processing for the full year for the full eastern Snake Plain). The total for remote sensing is therefore about \$100,000. Set-up and time for aggregation of ET results via GIS results in a total remote sensing cost of \$105,000. Using these figures, the estimated cost ratio of remote sensing to the current measurement program is $\$105,000/\$500,000 = 0.21$, i.e., remote sensing costs about 20% of the measurement costs. Measurement costs are for a subset of the total number of wells, all of which are not measured in a single year, whereas,

METRIC™ data cover the entire Snake River Plain and all places of use. The use of METRIC™ ET will not replace the existing measurement program, per se. Pumpage data that can be related to individual water rights will be needed for regression against the METRIC™ ET data for the same water rights to establish the relationship between volume pumped and volume of ET. That relationship can then be applied to all other non-monitored water rights and their associated wells to estimate both aquifer depletion and water use by individual water rights.

SUMMARY AND CONCLUSIONS

METRIC™ and SEBAL use digital image data collected by Landsat and other remote-sensing satellites that record thermal infrared, visible and near-infrared radiation. ET is computed on a pixel-by-pixel basis for the instantaneous time of the satellite image. The process is based on a complete energy balance for each pixel, where ET is predicted from the residual amount of energy remaining from the classical energy balance, where $ET = \text{net radiation} - \text{heat to the soil} - \text{heat to the air}$.

In Phase 1 for the Bear River Basin, the difference between METRIC™ (derived from SEBAL) and the lysimeter, total, for the growing season was 4%. For the Phase 2 comparison with precision weighing lysimeters at Kimberly, differences were less than 2%. These comparisons represent a small sample, but are probably typical. Error as high as 10 to 20%, if distributed randomly, could probably be tolerated by IDWR and by the water user communities.

Comparisons of METRIC™ predicted ET with precision weighing lysimeter data at Kimberly, Idaho from the 1980's and early 1990's have provided valuable information on the conditions required to obtain maximum accuracy with METRIC™ and the best procedure for obtaining ET monthly and annually. ET has been calculated for the entire Snake River Plain of southeastern Idaho and has improved the calibration of ground-water models by providing better information on ground-water recharge as a component of water balances. Ground-water pumpage from over 10,000 wells has been estimated using ET from METRIC™ by developing correlations between ET and pump discharge at measured wells and then extrapolating over large areas using ET maps from METRIC™.

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